### AE51A-03 0835h

## Sprites and lightning observation system installed at ESRANGE, Kiruna

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Activities of sprites and elves were first recorded in the west coast of Japan when a cold front passed over Japan by Tohoku University group in 1998. This fact strongly predicts occurrence of sprites and elves in other areas in wintertime, such as Northern Scandinavia where large positive CGs are occurring in wintertime. Once sprites and/or elves in the polar region are detected, it would be expected that many important phenomena are occurring: the interaction between the lightning-induced phenomena and the polar ionosphere/magnetosphere by electron density enhancement and by field-aligned current connection, high energy particle supply to the magnetosphere and so on. In order to conduct the sprites/elves imaging in the polar region, we improved an image-intensified CCD camera at ESRANGE, Kiruna, Sweden in August 2003, and also installed VLF receiver there. Further, we set up 2-components ELF receivers as the third station of the ELF world network of Tohoku University. All equipments are remotely controlled from Japan using network. A careful examination of Scandinavian lightning data provided by SINTEF and ELF recordings by Tohoku University shows there exist some strong cloud-ground discharges with a sufficient charge moment to produce sprites in January and February in the polar region.

### AE51A-04 0850h INVITED

## Role of Neutral Density and Conductivity Perturbations in Determining Sprite Initiation Locations

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Multiple sprites are often observed to occur simultaneously, laterally displaced from the underlying causative cloud-to-ground (CG) lightning discharge. The causes of this lateral displacement are presently not understood. This paper investigates the role of neutral density perturbations in determining the locations of sprite initiation. The work was motivated by two previous studies: (1) A detailed statistical showing that the distribution of sprite offsets relative to the underlying lightning had a mean of 40 km [São Sabbas et al., 2003]. (2) A follow-up study for the same observations showing that the maximum sprite and -CG production of the system were simultaneously reached at the time of maximum contiguous cloud cover of the coldest region, corresponding to the period of greatest convective activity of the system [São Sabbas and Sentman, 2003]. Thunderstorm convective activity is a potential source of gravity waves and mesospheric turbulence, which create an inhomogeneous neutral density background. For this paper computer simulations of the temporal-spatial evolution of lightning-induced electric fields in an inhomogeneous mesospheric neutral density and conductivity were performed. The results indicate that electrical breakdown is facilitated in isolated regions of density depletions at sprite initiation altitudes. These spatially distributed breakdown regions provide the seed electrons necessary for sprite generation, and may account for the observed sprite offsets. Furthermore, neutral density depletions may play a critical role in setting the overall sprite activity level above a thunderstorm.

### AE51A-05 0910h INVITED

## Remote Sensing of the Mesosphere by Means of Telescopic Observations of Sprites

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Telescopic imaging of sprites reveals fine structure covering a wide range of morphologies and time scales [*Gerken et al.*, 2000]. Theoretical explanations of observed spatial fine structures and diffuse glow in sprites were put forth in the context of a streamer-based model of electrical breakdown above thunderstorms [*Raizer et al.*, 1998; *Pasko et al.*, 1998]. Streamer properties depend on the background electron, ion and neutral atmospheric densities as well as the polarity of the streamer. In high altitude discharges such as sprites, which may extend over an altitude span of 50 - 100 km, the atmospheric neutral density decreases exponentially with altitude while the electron number density exponentially increases with altitude. Consequently, streamer properties are observed to vary throughout the altitude extent of a sprite. Theoretically, it should be possible to use observed streamer properties to gain insight into the natural background densities in the vicinity of a sprite. Since this region of the atmosphere is particularly difficult to study by other methods, sprites may thus serve as a useful tool in collecting data on the atmospheric composition at mesospheric altitudes. Many sprites were observed by the Stanford University telescopic imager during a large storm on July 13, 1998. Case studies of selected sprite events during this storm are presented and the relationships between observed sprite properties and parameters of the mesosphere are discussed.

### AE51A-06 0930h

## Observations of Thunderstorm Effects on Middle-Atmosphere Ionizable Constituents

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A coordinated rocket and ground-based program to investigate the effects of nearby thunderstorm activity on middle-atmosphere ionizable constituents was conducted at Wallops Island, VA. The first rocket payload was launched in darkness at 0632 UT on May 10, 2002. On the previous evening a significant weather front passed over the Appalachian mountains in Virginia approximately seven and a half hours before the time of the rocket launch. The front continued eastward to the Eastern Shore of Virginia and passed the rocket apogee location about three hours before the launch. A ground-based optical imager provided by Clemson University observed spherical wave structure in both the 557.7 nm and OH images after the front had passed over the launch range. An identical payload was launched at 0626 UT on May 16, 2002. There was no tropospheric convective activity in the area at the time of this launch or during the entire preceding evening. No obvious spherical wave structure was seen in the imager data during this evening. Four Gerdien condenser instruments, which measured ion conductivity, mobility, and concentration, were located at the front of each payload. Positioned in the center electrode of each Gerdien condenser was an RF-excited UV source. A different rare gas and window combination used with each lamp provided the sources for investigating the ionization/photodetachment properties of the aerosols. The lamp wavelengths ranged from 123.6 nm (10 eV) to 365 nm (3.4 eV). The payload also included a fixed-bias Langmuir probe for observation of both the background and lamp-induced electron concentrations. Absolute calibration of the Langmuir data was provided by an on-board Faraday radio-wave propagation experiment. While the main focus of the experiment was to identify thunderstorm-associated effects on mesospheric particles, the data during the disturbed evening additionally showed a significant change in the concentration of gas-phase ions (presumably, NO+) produced by the 123.6-nm UV source. This difference in response between the two evenings is thought to be related to changes in the neutral density temperature, produced either by gravity waves or electrostatic heating from the thunderstorm activity.

### AE51A-07 0945h

## The Upward Directed Poynting Flux over a Thunderstorm

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In August of 2002, NASA carried out the Altus Cumulus Electrification Study (ACES) to investigate the lightning/storm relationship, to quantify the storm electrical budget, and to validate the TRMM lightning sensor (LIS) data. The platform was General Atomic's Altus uninhabited aerial vehicle (UAV) which allowed long-duration, close-proximity monitoring of storms from their births to deaths. The platform carried a set of DC Field Mill sensors to measure electrostatic fields, AC electric and magnetic field sensors for deriving the Poynting flux, a Gerdien conductivity probe, optical sensors, and a flight payload data system. The data system collected low rate data, and also cloud be event-triggered into high rate mode for approximately 0.3 seconds about lightning strikes. During the month long mission, 11 scientific flights occurred yielding over 4300 high rate triggered events. An objective of this study was to determine the amount of upward radiated power into the middle atmosphere and ionosphere, and determine contribution of the radiated power to the global atmospheric electric circuit. In this work, we show upward Poynting flux measurements between 10 Hz -100 kHz from some specific thunderstorm overflights. We find that upward radiated powers from lightning strikes can be large. However, displacement currents are also comparatively large, suggesting that the radiation impedance above a thunderstorm is relatively low ( 150 Ohms at 10 kHz). This radiation impedence is calculated as a function of frequency. The effect of the radiated power on the global circuit will be discussed.

# AE51B MCC: 3010 Friday 1020h

## The Physics of Lightning and Storm Electrification III *(joint with A, NG)*

***Presiding:*** **L D Carey,** Texas A&M University**; A Jacobson,** Los Alamos National Laboratory

### AE51B-01 1020h INVITED

## Model Studies of Lightning in Thunderstorms

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The OU/NSSL cloud-scale model has a microphysics package designed to treat a variety of convective events and has numerous noninductive graupel-ice charge separation schemes based on different laboratory results. Other features are a branched 3-D lightning scheme and a recently-added explicit treatment of small ion processes. Model results suggest that lower charge regions can be generated by either inductive or noninductive processes. Inductive graupel-droplet interactions were

previously found to be able to generate a sufficiently strong lower positive charge region to cause negative cloud-to-ground ($-$CG) flashes to occur. However, the method used to diagnose ice crystal number concentration might underestimate the number of crystals at higher temperatures ($-15$–$0^{\circ}$C). If a minimum ice crystal concentration ($\sim 50\,\mathrm{L}^{-1}$) is assumed, then the noninductive graupel-ice mechanism acting alone is able to generate a lower positive charge center, also leading to $-$CG flashes. The result indicates a need for a more detailed (and, it is hoped, more accurate) microphysical treatment of ice crystals in the model. A small Florida storm simulation used a 9 August 1991 sounding from CaPE. The modeled storm compares well with radar and electrical observations of storms on that day. The simulation produced IC and $-$CG lightning flashes. The warm rain process forms rain drops that freeze when they are carried by the updraft to $T < 0^{\circ}$C. The frozen drops rime and separate charge via noninductive and/or inductive processes. The presence of large ice particles at low levels results in a rapid formation of a lower positive charge region and initially negative $E_z$ at the surface. The 29 June 2000 supercell storm observed during the STEPS field program has also been simulated. Both the observed and modeled storms had strong updrafts and midlevel rotation, produced many +CG lightning flashes, and had a strong correlation between updraft volume and total flash rate.

URL: http://www.cimms.ou.edu/~mansell/

**AE51B-02 1050h**

## Initial Electrification of Thunderstorms: Evidence for a Connection Between Precipitation and Electrical Charging

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In this study we investigate the initial electrification of three thunderstorms using surface electric field (E) measurements, radar measurements, lightning mapping array data, and in situ balloon E soundings. Our data support previous results and show a close correlation between the location of the developing precipitation core and the location of the early charges in each storm. In one cell the initial deflection of the surface E was in the direction of enhanced fair weather (negative) E, indicating an inverted dipolar charge distribution overhead. During this time, the only substantial precipitation (e.g., greater than 40 dBZ echo) was located below the altitude of the -10$^{o}$C isotherm. This suggests that the charging in the mixed phase region was occurring at temperatures warmer than the charge reversal temperature. In addition, the first two balloon soundings in this cell indicate that the lowest charge was positive and moved downward, and thus was presumably carried on precipitation. As precipitation subsequently developed in colder parts of the cloud, the surface E became dominated by a normal dipole. The first lightning flash was a normal intracloud flash within and above the developing precipitation core. Multiparameter radar coverage for the second case began just after the initial deflection in the surface E. The initial E deflection was in the foul weather direction, as for a normal positive dipole growing overhead. At the same time, upward growth of a substantial precipitation core occurred, with much of the core located above the altitude of -10$^{o}$C. The first lightning flash in this cell was a normal intracloud flash within and above the developing precipitation core. In the third case, an early explosive precipitation growth phase occurred between 6 and 8 km altitude. A balloon sounding during this growth phase and before the first lightning flash revealed a normal dipole structure, with positive charge centered at 8.7 km (-20$^{o}$C) and negative charge centered at 7.4 km (-10$^{o}$C). The first lightning flash initiated at 8.8 km and revealed positive charge above the precipitation core (and near the top of the updraft) and negative charge beside the precipitation core, in agreement with the balloon sounding. The data from these three cases support the idea that precipitation particles and electrical charge develop together during the initial electrification of thunderstorms.

**AE51B-03 1105h**

## Memory effect in the collisional charging of ice

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The theory of collisional charging of ice describes the formation of charge bilayers on ice due to rapid vapor growth[1]. OH- ions are bound at crystal edges and corners, and positive ions are distributed deeper in the ice. Charge transfer results from rebounding collisions which cause temporary melting of the surface, liberating the OH- ions into the liquid. On separation, the particles take approximately equal shares of the melt, thus the particle that had a greater density of negative surface ions loses more negative charge. The theory achieves quantitative agreement with experiment [3], with only one empirical constant, relating to the probability of ionization vs surface roughness. The theory explains the polarity rule' developed from laboratory studies: The particle experiencing faster vapor growth becomes positively charged [2]. However, further analysis now leads us to elaborate the theory. Surface roughness is semipermanent as long as temperature stays well below melting [4], because annealing to smooth facets is a collective process, virtually impossible to achieve by the diffusion of independent single atoms. Therefore, rapid vapor growth accumulates disordered layers, building to a thickness proportional to the growth rate and the duration of the growth. This explains why, in a series of repetitive collisions, the charge transfer increased over a period of several minutes between events [4]. Consequently, we amend the polarity rule: In a rebounding collision, the particle which had experienced the greater time-integrated vapor growth rate becomes positively charged, if temperature has remained continuously colder than a few degrees below 0o C. A surface initially disordered will continue disordered growth during slow deposition, by virtue of epitaxy with the underlying roughness. [1] J.G. Dash, B.L. Mason and J.S. Wettlaufer, Theory of charge and mass transfer in ice-ice collisions, J. Geophys. Res. 106, 20395-20402 (2001); J.G. Dash and J.S. Wettlaufer, The surface physics of ice in thunderstorms, Can. J. Phys. 81, 201-207 (2003). [2] B. Baker, M.B Baker, E.R. Jayaratne, J. Latham and C.P.R. Saunders, The influence of diffusional growth rates on the charge transfer accompanying rebounding collisions between ice crystals and soft hailstones, Quart. J. Roy. Met. Soc. 113, 1193-215 (1987), and references therein. [3] B.L. Mason and J.G. Dash, Charge and mass transfer in ice-ice collisioms: experimental observations of a mechanism in thunderstorm electrification, J. Geophys. Res. 105,10185-10192 (2000). [4]. Reference 3, Fig.5.

**AE51B-04 1120h INVITED**

## Results of Rocket-Triggered Lightning Studies at Camp Blanding, Florida: An Update

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In this review, we present selected results of triggered-lightning experiments at the International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida. After a general update, the following three topics will be covered in more detail. (1)Mechanism of cutoff and re-establishment of current in rocket-triggered lightning. We will present evidence (electric and magnetic fields, channel-base current, time-resolved optical records) that the gap resulting from the vaporization of the triggering wire by the upward positive leader current is bridged by a leader/return-stroke type process (Rakov et al., 2003). Characterization of the attempted interruption and following re-establishment of current to ground in rocket-triggered lightning may have important implications for the understanding of channel current cutoff in natural lightning flashes and may provide new insights into the formation of strokes occurring in the same channel within a millisecond or less. (2)Estimation of input energy in rocket-triggered lightning. In 2000, the electric fields in the immediate vicinity (within 0.1 to 1.6 m) of the triggered lightning channel were measured with Pockels sensors (Miki et al., 2002). We used these fields and associated currents measured at the base of a 2-m strike object to compute power and energy, each per unit channel length and as a function of time (up to 10 ms), associated with return strokes in rocket-triggered lightning. In doing so, we assumed that the vertical component of the electric field at horizontal distances of 0.1 to 1.6 m from the lightning attachment point is not much different from the longitudinal electric field inside the channel (Borovsky, 1995). The estimated mean input energy over the first 50 s or so is between 1 and 10 kJ/m, consistent with predictions of gas dynamic models. (3)Multiple-station measurements of electric and magnetic fields and their time derivatives produced by close natural lightning discharges. In 2002, the field measuring network established at the ICLRT in 1997 was upgraded to include field derivative measurements, optical coverage, and measurements of current in a grounded structure in response to nearby lightning strikes. The network currently includes measurements at 11 locations and covers an area of approximately 0.5 sq. km. In 2002, data were obtained for 11 cloud-to-ground flashes, including a three-stroke bipolar flash. This bipolar flash consisted of two positive strokes in separate channels followed by a negative stroke along the second-stroke channel. Selected data acquired in 2002 and 2003 will be presented.

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**AE51B-05 1150h**

## Possible Interpretations of VLF-LF Radiation Waveshapes Produced at the Initial Stage of Lightning Discharges

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Observations of lightning discharges from many 10s to a very few 100s of kilometers show that impulsive electric field changes (VLF-LF) can be symmetrically bipolar or asymmetrically “unipolar” at the initial stages of the discharges. The waveshape tends to be more bipolar at the very beginning of the discharges and tends to become increasingly “unipolar” as discharges develop. We suspect that the possible physical reason behind these phenomena is the length of the conducting lightning channel. Each observed radiation pulse is apparently associated with an impulsive breakdown process, which would launch a current pulse propagating backward into the existent conducting channel. As the current propagates, its amplitude is expected to decrease continuously along the channel. At the very beginning of a discharge, the existent channel is short and less conductive, and the breakdown current pulse is attenuated quickly and is effectively constrained into a local range. A current oscillating at a local point will produce a symmetric bipolar radiation pulse. As the discharge develops, the channel becomes longer and more conductive, and a propagating, less attenuated current pulse will produce a radiation pulse similar to the shape of the current pulse itself, or a “unipolar” pulse [Uman et al., 1975]. In this presentation, we will show some field change observations and will compare them with modeled pulse shapes. Reference: Uman, M.A., D.K. McLain, and E.P. Krider, The electromagnetic radiation from a finite antenna, Am. J. Phys., 43, 33-38, 1975.



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**AE51B-06 1205h**

### New x-ray observations of triggered lightning

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We report preliminary results from the x-ray observations of rocket-triggered lightning made in the summer of 2003 at the International Center for Lightning Research and Testing at Camp Blanding, FL. A total of 26 dart leader/return stroke sequences were observed, using eight NaI(Tl)/PMT detectors plus two identical control detectors with no scintillator. The detectors were enclosed in five thick aluminum boxes, designed to keep out RF noise, water and light, and placed between 5 m and 650 m from the lightning channels. X-rays were measured 0 - 100 microseconds just prior to the return strokes in 73 percent of these events, supporting earlier measurements of energetic radiation from triggered lightning. Using bronze collimators and attenuators, the emission was found to be composed of multiple, very brief bursts of x-rays with energies extending up to about 200 keV, with each burst typically lasting less than 1 microsecond. The x-ray emission was also observed to be spatially and temporally associated with the dart leaders, with the brightest bursts coming from the direction of the dart leader when it was within about 50 m of the ground. Finally, for one triggered lightning event, an intense burst of gamma-rays, lasting more than 300 microseconds, with energies up to 10 MeV was observed during the initial continuous current phase, associated with a large current pulse, from a distance of 650 m from the launcher. These x-ray observations suggest that copious numbers of runaway electrons are commonly produced during lightning, implying that the electric fields associated with some phases of lighting may be much stronger than previously thought. These results have important implications for the physics of lightning discharges.